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USER'S MANUAL FOR CODES CHLG AND CHTS: STEADY INCOMPRESSIBLE VISCOUS FLOW IN TWO - DIMENSIONAL CHANNELS

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USER'S MANUAL FOR CODES CHLG AND CHTS:
STEADY INCOMPRESSIBLE VISCOUS FLOW IN TWO-DIMENSIONAL CHANNELS

This report is a user's manual for the two computer codes CHLG and CHTS for rapidly calculating steady incompressible viscous flow in two-dimensional channels. These codes were both developed under ONR contract N00014-76-C-0324, administered under the General Hydrodynamics Research Program of the David W. Taylor Naval Research and Development Center. Copies of both of these codes have been sent to NSRDC.

Code CHLG calculates laminar flow only in a channel with a general shape for the lower boundary. Code CHTS includes both laminar and turbulent flow options, the latter by a simple eddy viscosity model, but is limited to straight wall channels. Both codes provide for either Couette or Poiseuille inflow, and use a symmetry condition at the top of the mesh.

This manual will provide a description of input and output variables, plus key areas for possible modifications in the codes. The codes are not really user-oriented software, but are merely experimental codes used by the principal investigator in developing the semidirect methods for the given problems. Consequently, the codes will be short on comment cards, and will have "left-over" options from earlier experimentations. Given the limitation on time and money under this contract, it did not seem advisable to expend a great deal of effort in cleaning up the codes.

Code CHTS

Code CHTS calculates laminar or turbulent flow in a straight-walled channel. (As an option, it will also calculate flow in a steady slab piston, but the turbulent flow option is not operative for the piston face.) The input variables are of two kinds, in DATA statements and in a READ operation. The code is designed to be used on a time shared CDC 6600 computer system. At a certain point in the program, the code will print out a request for input variables which are typed in at the user terminal. The input variables which appear in two DATA statements in the main program appear below. Those marked with * are overwritten by the current form of the READ statement given later.

IL,JL These are the dimensions of the mesh in the x (stream wise) and the y directions. Currently, the variables are dimensioned for IL=JL=11. The rules for changing dimensions in the main program and in Subroutine EVP9 are obvious.

LIM Maximum number of iterations allowed, commonly set to 41.

NWBC This is the option indicator for the vorticity boundary condition at the no-slip (lower) wall. The suggested values are either NWBC = 2, which gives Woods' equation for wall vorticity, or NWBC = 6, which gives Israeli's method.

ELX*,ELY These are the dimensionless lengths of the channel in the x and y directions. Normally, the transverse height in y is the normalizing distance, so ELY = 1. The nominal value for ELX currently in the program is ELX = 200.

IPR This is the option indicator for the amount of printout. IPR = 0 gives a minimal printout including the maximum error due to the marching solution of the linear equations, the converged values of vorticity along the no-slip wall, as well as some indication of the wall vorticity at a single point and the rate of change of the convergence test during each iteration. IPR = 1 gives a full printout of the vorticity and stream function of the converged solution, as well as the full errors in the initial marching solution. IPR = 2 gives a great deal of additional printout, including the full influence coefficient matrix used in each of the two linear solutions. It is not recommended that IPR = 2 be used ordinarily.

ICOR This is the number of iterative corrections to be used <u>within</u> the marching solution for the linear equation. It is recommended that the nominal value of ICOR = 1 be used.

NIN This option sets the inflow boundary conditions at I = 1. NIN = 1 gives Couette flow, NIN = 2 gives Poiseuille flow, for NBIL ≠ 1. (See NBIL below.)

NRSTRT Not currently operative.

NSTACK* For NSTACK = 0, the initial conditions everywhere are set = inflow conditions. For NSTACK = 1, the initial conditions are set from the converged answer to the previous case. For the first case in a RUN, NSTACK = 0 is required.

CONV* This is the convergence criterion for the non-linear iterations nominally set equal to 5×10^{-4}. For coarse-mesh solutions, CONV = 10^{-3} is entirely adequate.

NT* NT = 0 gives laminar flow, NT = 1 gives turbulent flow calculated with a simple eddy viscosity model.

NBIL* NBIL $\neq$ 1 gives a developing channel flow problem, while NBIL = 1 gives a two-dimensional slab piston problem.

GFAC This is the multiplier for the theoretical under-relaxation factor for wall vorticity. The recommended value is GFAC = to 1.

GILFAC* This corresponds to GFAC for the piston face for the option NBIL = 1. The recommended value is GILFAC = 1.

JMDIR This parameter determines the direction for the marching solution for linear equation to be in the positive J direction for JMDIR = +1. The value JMDIR = -1 can also be used, but the error propogation is better for +1.

When the program is compiled and run, the print statement 1010 in the code prints out the label shown in format statement 905 which reads:

"ENTER RE,ELX,NT,NBIL,NSTACK,GILFAC;PLEASE"

The values of the variables are to be entered at the user's terminal. The definitions follow.

RE Reynolds number based on inflow channel height and bulk mixing velocity. If RE<0, the run is terminated normally.

ELX Dimensionless channel length in the stream-wise direction.

NT NT = 0 gives laminar flow, NT = 2 gives turbulent flow.

NBIL NBIL = 0 gives channel flow, and NBIL = 1 gives slab piston flow.

NSTACK = 0 for first case in a RUN. Afterwards, NSTACK = 1 sets initial conditions from the converged answers of the previous case.

GILFAC Multiplier for wall vorticity. GILFAC = 1 is recommended.

The output of the program comes in four parts. First of all there will be an echo of the input parameters. Next, there will be some output from the initial solution of the linear equation by the marching method in Subroutine EVP9. The most important of these are FEMAX for IEQ = 1 and 4, which are the maximum errors in stream function and vorticity, respectively. <u>These should be 10^{-4} or smaller in order to obtain reasonable solutions</u>. The sizes of these quantities are strong functions of the cell aspect ratio of the problem, which is determined primarily by the parameters IL,JL,ELX, ELY. A full description of the error propagation characteristics of the marching method will be found in the article "Marching Methods for Elliptic Problems, Part 1", Volume 1, No. 1, of <u>Numerical Heat Transfer</u> (1978), pg. 1.

The next set of output is printed at every iteration of the nonlinear method. The variables printed out are the iteration number NIT, and three indicators of the convergence behavior. The first is DQ, which is the maximum of the absolute value of the change in vorticity since the previous iteration. The next value is DQNORN, which is simply DQ/r where r is the under-relaxation factor for wall vorticity. It is this DQNORM which is actually tested for convergence. It is a more stringent test than testing for DQ, since a small value of the relaxation factor could possibly give an erroneous indication of convergence. For NWBC = 6, the wall vorticity is not actually under-relaxed, and DQNORM = DQ. The last value printed out at each iteration is Q(ILC), which is the actual value of vorticity along the no-slip wall in the middle of the mesh in the I direction.

When convergence is obtained, the fourth set of output is printed. The values of the mesh size, NIT, CPU time in sec, and CPU time per cell in milliseconds are printed. Then, the values of vorticity Q along the wall (that is, at J = 1) are always printed out at the completion of convergence. If the print option indicator IPR has been set = 1 or larger, this is followed by a full field printout of the variables stream function (S), vorticity (Q), and the velocity components U and V. The READ statement is executed again, to start another case; RE<0 will terminate the run normally.

A sample output sheet, including the variables input by the user from the terminal, appears on page 7.

Code CHLG

Code CHLG calculates laminar flow in a two-dimensional channel with an almost arbitrary description of the lower channel wall. This code requires the programs SGECO and SGESL from the LINPACK Library. The input variables of CHLG are very similar to those for Code CHTS, with the following exceptions.

The variables VRE,VG,NNRE and NNVG appear in DATA statements. These originally were used to parameterize the Reynolds number and the under-relaxation factor at the wall in DO-Loops. The options are now over-written by READ statements. The option indicator NMETH is set = 4 in a DATA statement in order to activate the Split NOS method. This is the only option that is now active. Rather then set the lengths ELX and ELY, as in the previous Code CHTS, the finite difference mesh increments DX and DY are set in a DATA statement, nominally DX = 2 and DY = 0.1. An additional print option occurs in the variable IPRGEO. For this value = 1 or greater, a detailed printout of the geometry of the channel is given, including the derivatives of the wall slope. The variable CELC which appears in the first DATA statement is used to define the length of the channel, and will be described below. The variable NSOUT which appears in the second DATA statement is an outflow boundary condition option. The value NSOUT = 2 is recommended.

The READ statement requests the operator as follows:

"ENTER RE,CELC,NJUMP,NWBC,GF,CONV;PLEASE. (RE<0 TO STOP)"

As before, RE is the Reynolds number based on the inflow channel height, and RE<0 terminates the RUN normally. CELC defines the length of the channel according to the relation ELC = RE/CELC. This makes the length of the channel to be proportional to the Reynolds number, allowing separated flow regions to be maintained within the computational domain. NJUMP acts as NSTACK in the previous Code CHTS, so NJUMP = 0 is required for the first case in a RUN. NWBC is again the boundary condition option on wall vorticity. Five different options are still active in the program, but the only recommended values are NWBC = 2 which gives Wood's equation for vorticity, NWBC = 3 which gives Jensen's equation, and NWBC = 6 which gives Israeli's condition. The variable GF is the multiplier for the theoretical under-relaxation factor for wall vorticity; the recommended value is GF = 1. CONV is the convergence criterion for the nonlinear solution; the recommended value is CONV = 10^{-3} for a coarse mesh.

The details of the channel geometry are set in Subroutine GEO. The currently used option is a channel that is defined in Subroutine CHAN5. If this option is not used, the statement CALL CHN5 in Subroutine GEO can be eliminated in favor of coordinates for the upper and lower surface, YU and YL respectively, being defined in DATA statements. Sample DATA statements of this type appear as COMMENT cards in Subroutine GEO. The currently active option in Subroutine CHAN5 defines the lower wall of the channel based on a hyperbolic tangent function. The wall derivatives which are necessary for the non-orthogonal coordinate transformation are evaluated numerically in Subroutine GEO. The order of this numerical differentiation is set by the parameter IODIF, which is set = 6 at line 24 of Subroutine GEO. This gives 6-th order differentiation. Values of IODIF = 2 or 4 could also be used.

With the exception of the channel geometry data which is printed out for IPRGEO = 1, the output for Code CHLG is similar to the output described above for Code CHTS. Additional final output is the value UWALL = slip velocity at the lower wall (which is identically = 0 in the completed converged case) and the % deviation of the vorticity solution from Poiseuille flow. A sample output sheet is given on page 8.

```
FTN,I=CHTS,OPT=2
      7.902 CP SECONDS COMPILATION TIME
/LGO
 IN CHTS, IL= 11 JL= 11 LIM= 41 IPR= 0 ICOR= 1 CONV=   .10E-02
           JMDIR=  1

   ENTER:   RE,ELX,NT,NBIL,NSTACK,GILFAC;  PLEASE
? 1000.,200.,1,0,0,1.

 RE=1000.0  ELX,ELY=200.0  1.0 ;DX,DY= 20.00   .10 ;AR=200.00 G=  .100
 NWBC= 6 NT= 1  NBIL= 0  UWALL=  0.0  GIL=20.000
 ++++  TURBULENT CALCULATION  ++++
 NWBC=6, WITH GWIT =   2.000
 IN EVP,  IEQ= 4 FEMAX=   .1070E-12
 IN EVP,  IEQ= 1 FEMAX=   .1279E-12
 NIT=  1 DQ=  .2000E+01 DQNORM=  .2000E+01 Q(ILC,1)=  2.000000
 NIT=  2 DQ=  .1651E+01 DQNORM=  .1651E+01 Q(ILC,1)=  3.650843
 NIT=  3 DQ=  .1367E+01 DQNORM=  .1367E+01 Q(ILC,1)=  5.017947
 NIT=  4 DQ=  .9371E+00 DQNORM=  .9371E+00 Q(ILC,1)=  5.955027
 NIT=  5 DQ=  .4552E+00 DQNORM=  .4552E+00 Q(ILC,1)=  6.410266
 NIT=  6 DQ=  .1656E+00 DQNORM=  .1656E+00 Q(ILC,1)=  6.526983
 NIT=  7 DQ=  .5956E-01 DQNORM=  .5956E-01 Q(ILC,1)=  6.520556
 NIT=  8 DQ=  .3190E-01 DQNORM=  .3190E-01 Q(ILC,1)=  6.488662
 NIT=  9 DQ=  .3286E-01 DQNORM=  .3286E-01 Q(ILC,1)=  6.455802
 NIT= 10 DQ=  .2613E-01 DQNORM=  .2613E-01 Q(ILC,1)=  6.429673
 NIT= 11 DQ=  .1816E-01 DQNORM=  .1816E-01 Q(ILC,1)=  6.411513
 NIT= 12 DQ=  .1161E-01 DQNORM=  .1161E-01 Q(ILC,1)=  6.399905
 NIT= 13 DQ=  .6957E-02 DQNORM=  .6957E-02 Q(ILC,1)=  6.392948
 NIT= 14 DQ=  .3918E-02 DQNORM=  .3918E-02 Q(ILC,1)=  6.389030
 NIT= 15 DQ=  .2345E-02 DQNORM=  .2345E-02 Q(ILC,1)=  6.386981
 NIT= 16 DQ=  .1899E-02 DQNORM=  .1899E-02 Q(ILC,1)=  6.386022
 NIT= 17 DQ=  .1499E-02 DQNORM=  .1499E-02 Q(ILC,1)=  6.385663
 NIT= 18 DQ=  .1159E-02 DQNORM=  .1159E-02 Q(ILC,1)=  6.385613
 NIT= 19 DQ=  .8830E-03 DQNORM=  .8830E-03 Q(ILC,1)=  6.385706
 IL,JL= 11 11 NIT= 19 CPU TIME=    .841 CPU TIME PER CELL= 8.410 MSEC
   .200000E+01   .633089E+01   .638495E+01   .638568E+01   .638570E+01   .638571E+01
                 .638571E+01   .638571E+01   .638571E+01   .638571E+01   .638571E+01

   ENTER:   RE,ELX,NT,NBIL,NSTACK,GILFAC;  PLEASE
? -1,1,1,1,1,1
     .853 CP SECONDS EXECUTION TIME
/
```

```
. FTN,I=CHLG,OPT=2
     11.420 CP SECONDS COMPILATION TIME
/LGO
 ENTER RE,CELC,NJUMP,NWBC,GF,CONV;PLEASE. (RE<0 TO STOP)
? 1000.,3.,0,6,1.,1.E-03
 NIN= 2 NSOUT= 2 NRST= 40 NSTACK= 0 TOL= .1E-03
 CELC=   3.000  ELC=RE/CELC FOR SCALING; CONV= .1E-02
 CHANS, XCR =     .200E+00  FSC = 10.00
 IN GEO, WALL DERIVATIVES EVALUATED BY IDDIF= 6


 NRE=  1      RE=    .1000E+04   DX=    .3333E+02   DY=    .1000E+00   G=    1.0000
 SPLIT NOS                 WALL BC OPTION NO. 6

 NWBC= 6, WITH GWIT=  2.000
 RCOND=       .428371518124031E-01
 IN EVP10,IEQ= 4 FEMAX=  .250122E-11
 RCOND=       .997668960533680E+00
 IN EVP10,IEQ= 1 FEMAX=  .234479E-12
 NIT=  0 DQ=  .2434E+01 DQNORM=  .2434E+01 Q(ILC,1)=   .731952
 NIT=  1 DQ=  .1108E+01 DQNORM=  .1108E+01 Q(ILC,1)= -.107800
 NIT=  2 DQ=  .5451E+00 DQNORM=  .5451E+00 Q(ILC,1)= -.177841
 NIT=  3 DQ=  .4559E+00 DQNORM=  .4559E+00 Q(ILC,1)=   .020898
 NIT=  4 DQ=  .1542E+00 DQNORM=  .1542E+00 Q(ILC,1)=   .085050
 NIT=  5 DQ=  .1059E+00 DQNORM=  .1059E+00 Q(ILC,1)=   .154033
 NIT=  6 DQ=  .5271E-01 DQNORM=  .5271E-01 Q(ILC,1)=   .149927
 NIT=  7 DQ=  .3234E-01 DQNORM=  .3234E-01 Q(ILC,1)=   .131724
 NIT=  8 DQ=  .1885E-01 DQNORM=  .1885E-01 Q(ILC,1)=   .126621
 NIT=  9 DQ=  .8448E-02 DQNORM=  .8448E-02 Q(ILC,1)=   .128251
 NIT= 10 DQ=  .5298E-02 DQNORM=  .5298E-02 Q(ILC,1)=   .130656
 NIT= 11 DQ=  .3376E-02 DQNORM=  .3376E-02 Q(ILC,1)=   .131708
 NIT= 12 DQ=  .1423E-02 DQNORM=  .1423E-02 Q(ILC,1)=   .131479
 NIT= 13 DQ=  .9121E-03 DQNORM=  .9121E-03 Q(ILC,1)=   .130962
 IL,JL= 11 11 NIT= 13 CPU TIME =     .724 CPU TIME PER CELL = 7.240 MSEC
 QWALL AND UWALL FOLLOW
   .300000E+01  .152359E+01  .143576E+00 -.115882E+00 -.442829E-01  .130962E+00
                .246201E+00  .382672E+00  .425282E+00  .533015E+00  .537695E+00

  0.            .976383E-05 -.287660E-03 -.124750E-03 -.140475E-03 -.120224E-03
               -.933845E-04 -.647472E-04 -.686358E-04 -.490483E-05 0.

 % DEVIATION FROM FULLY DEVELOPED POISEUILLE FLOW
  0.           -.374026E+02 -.892318E+02 -.113795E+03 -.105904E+03 -.821078E+02
               -.659929E+02 -.466594E+02 -.401951E+02 -.243871E+02 -.243871E+02

 ENTER RE,CELC,NJUMP,NWBC,GF,CONV;PLEASE. (RE<0 TO STOP)
? -1,1,1,1,1,1
       .748 CP SECONDS EXECUTION TIME
/
```